



ARL-TN-0872 • FEB 2018



US Army Research Laboratory

Ballistic V_{50} Evaluation of TIMET Ti108

by John Hogan

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Weapons and Materials Research Directorate, ARL

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) February 2018		2. REPORT TYPE Technical Note		3. DATES COVERED (From - To) 1 June 2017–30 December 2017	
4. TITLE AND SUBTITLE Ballistic V ₅₀ Evaluation of TIMET Ti108				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) John Hogan				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Research Laboratory Weapons and Materials Research Directorate (ATTN: RDRL-WMP-E) Aberdeen Proving Ground, MD 21005				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TN-0872	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT A ballistic V ₅₀ evaluation of an experimental titanium alloy Ti108 was conducted to determine if lower alloys in a plate's content can provide slightly lower strengths with higher elongation and resistance to cracking while still meeting the minimum performance specifications outlined in MIL-DTL-46077G. A 3.1-inch-thick plate was provided by the Titanium Metals Corporation (Dallas, Texas) for the V ₅₀ evaluation. The projectiles used for the evaluation were the 20-mm M602 armor piercing with tracer (AP-T) and a 30-mm armor piercing discarding sabot (APDS). It was found that the Ti108 plate did not meet the minimum ballistic requirements for the 20-mm M602 AP-T threat, but did meet the requirement for the 30-mm APDS threat by 1 m/s. Future studies or adjustments to the chemistry of the Ti108 can be conducted to optimize ballistic performance.					
15. SUBJECT TERMS V50, titanium alloys, Ti108, 30-mm APDS, armor piercing discarding sabot, 20-mm M602 AP-T, armor piercing with tracer					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 46	19a. NAME OF RESPONSIBLE PERSON John Hogan
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) (410) 278-6953

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Acknowledgments

I would like to thank Mr Matthew Burkins (US Army Research Laboratory) for acquiring and providing the materials needed for this evaluation, along with Mr Charles “Hugh” Walter and Mr David Handshoe (Bowhead Science and Technology, LLC) for their help and expertise.

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1. Introduction

V₅₀ evaluations are conducted to compare the ballistic performance of different titanium alloys. Conventional Ti-6Al-4V is commonly used in aerospace frames and engine components, but has difficulty passing ballistic shock testing on welds as cracking initiates in the welds and runs through parent body material. To see if a lower alloy content plate can provide a slightly lower strength with higher elongation and resistance to cracking, TIMET (Titanium Metals Corporation, Dallas, Texas) provided a 12-inch × 27-inch × 3.1-inch sample plate of an experimental alloy called Ti108 for V₅₀ evaluation (Fig. 1, front view; Fig. 2, rear view). The plate chemistry and mechanical testing data were collected by TIMET and are provided in Tables 1 and 2, respectively.

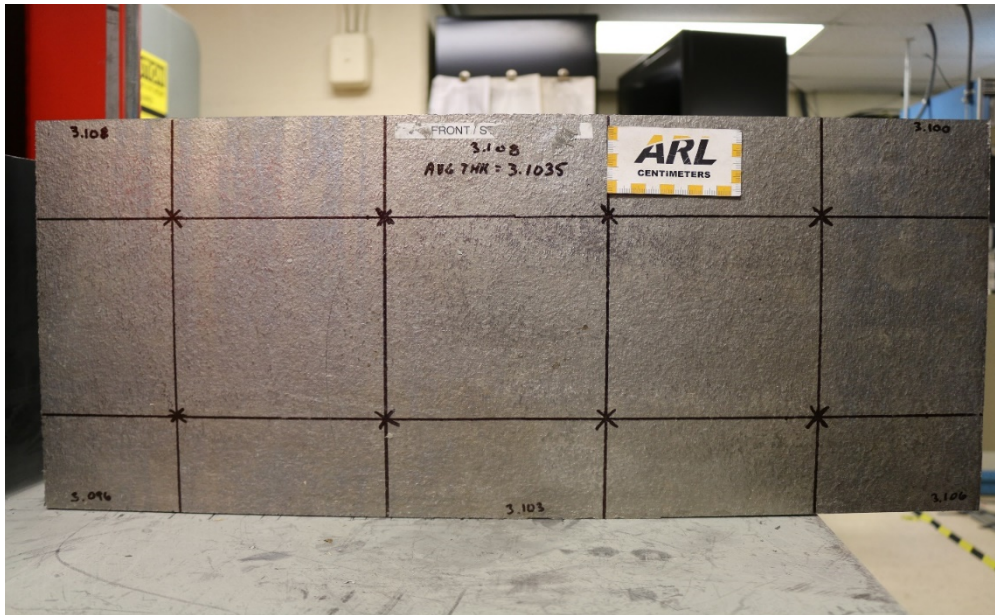


Fig. 1 Ti108 strike face (front of plate)

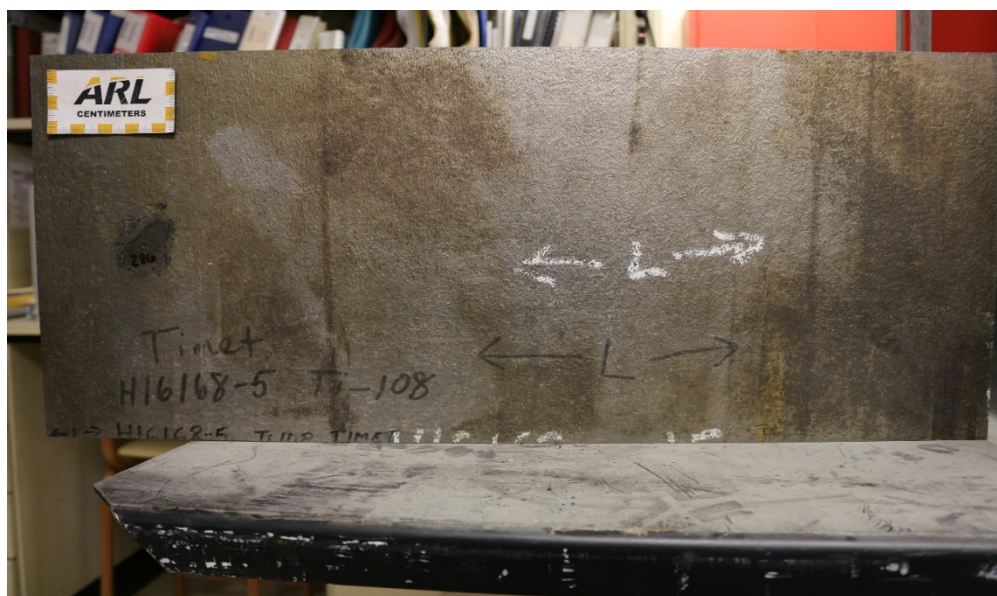


Fig. 2 Ti108 rear (back of plate)

Table 1 Chemistry of Ti108, heat no. H16168

Ingot location	Element, wt%											
	Al	C	Cr	Fe	Mo	N	Ni	O	Si	Sn	V	T _β , F ^A
Top	4.73	0.005	0.002	0.534	0.001	0.004	0.0042	0.177	0.014	<0.005	2.99	1778
Top-middle	4.75	0.005	0.002	0.534	0.001	0.004	0.0041	0.179	0.014	<0.005	2.99	1780
Middle	4.76	0.005	0.002	0.548	0.001	0.003	0.0043	0.184	0.016	0.005	3.01	1780
Bottom-middle	4.74	0.004	0.002	0.609	0.002	0.004	0.0049	0.171	0.016	<0.005	3.05	1772
Bottom	4.75	0.004	0.002	0.592	0.002	0.004	0.0052	0.172	0.016	<0.005	3.05	1773
Average:	4.74	0.005	0.002	0.563	0.001	0.004	0.0045	0.177	0.015	0.005	3.02	1777

Note: Ingot chemical analysis results

8000 lb 32-inch diameter triple vacuum arc remelting processed ingot

^A Calculated from binary equilibrium diagrams using the empirical formula

$T_{\beta} \{^{\circ}\text{F, wt}\%\} = 1607 + 39.3\text{Al} + 330\text{O} + 1145\text{C} + 1020\text{N} - 21.8\text{V} - 32.5\text{Fe}$

Table 2 Tensile properties: mechanical test data for Ti108, heat no. H16168

Orientation	Tensile yield strength		Ultimate tensile strength		Elongation	Reduction of area
	ksi	MPa	ksi	MPa	%	%
L	111	765	125	862	13	23
T	111	765	124	855	11	19

2. Experimental Procedure

A standard V_{50} was conducted on the TIMET Ti108 plate per Military Standard MIL-STD-662F.¹ The Ti108 plate was secured with clamps to a 50.8-mm-(2-inch) thick 90° stand (Fig. 3) to maintain a 0° obliquity. A 0.5-mm (0.020-inch) 2024AL witness plate was placed 152 mm (6.0 inches) behind and parallel to the rear of the Ti108 plate (Fig. 4). If the witness plate was impacted by the target or penetrator material causing light to pass through the sheet, the shot was considered a complete penetration (loss). If no light was seen through the sheet, even if damaged, this was considered a partial penetration (win). Projectile impact velocities and total yaw were measured with flash X-rays.² Impacts where the total yaw was greater than 3° were not used for the V_{50} calculation.



Fig. 3 Titanium plate in target stand (front view)



Fig. 4 Titanium plate in target stand (side view)

The projectiles used for this evaluation were the 30-mm armor piercing discarding sabot (APDS) core (Fig. 5) and the 20-mm armor piercing with tracer (AP-T) M602 (Fig. 6).

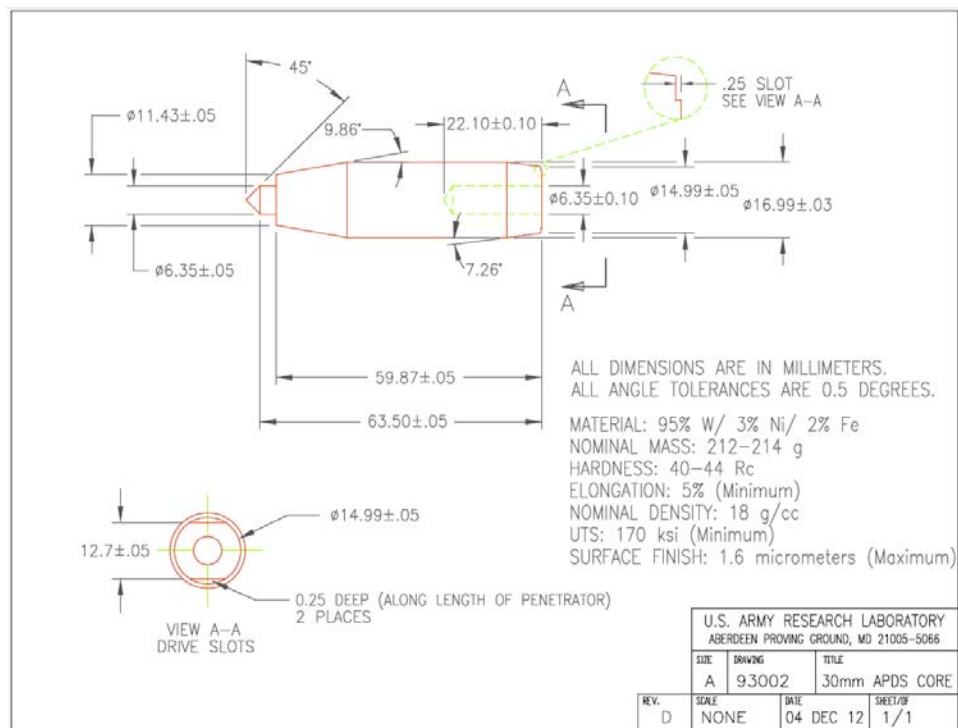


Fig. 5 30-mm APDS core

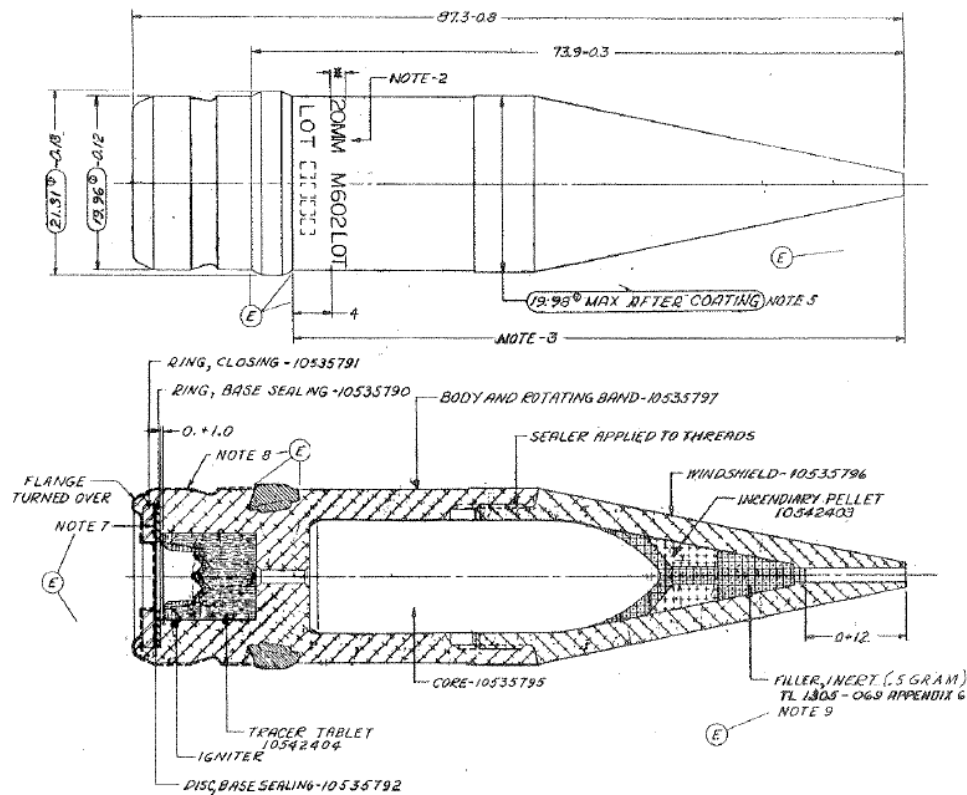


Fig. 6 20-mm AP-T M602

The 30-mm APDS core was sabot-launched out of a 10-ft-long smooth bore lab gun, chambered for a 37-mm cartridge case, with a 1.090-inch-diameter bore. M2 165-mm propellant was used as the propelling charge and load weights were varied to vary the projectile impact velocity.

The M602 projectiles were pulled from M601 cartridges and were separately loaded into an 8-ft-long 20-mm diameter rifled lab gun chambered for a 25-mm case. MPM2 37-mm propellant was used as the propelling charge and load weights were varied to vary the projectile impact velocity.

Military Detail Specification MIL-DTL-46077G³ was used in determining a starting velocity in relation to the thickness of the target plate. Starting velocities of 1007 m/s (3303 ft/s) for the 30-mm APDS and 1050 m/s (3444 ft/s) for the M602 projectiles were selected and adjusted up or down depending on the result being a complete penetration (CP) or partial penetration (PP). Since a CP was determined on the initial shots of both projectiles, the impact velocities for subsequent shots were lowered until a PP was achieved. Once a PP was achieved, the process of increasing velocity after a PP and decreasing velocity after a CP continued until enough shots were taken so that a V_{50} could be calculated.

3. Results and Analysis

Prior to the evaluation, the Ti108 plate's thickness was measured in all 4 corners, 1-inch in from the sides, and averaged. A Brinell hardness (HBW) measurement was also taken and the results are listed in Table 3.

Table 3 Average measured thickness and HBW for Ti108 plate

Target Description	Average measured thickness (mm)	Average measured thickness (inches)	HBW
Ti108 = Ti-5Al-3V-0.6Fe-0.18O	35.9	3.1035	286

The V_{50} results for the 30-mm APDS are given in Table 4 and the standard deviation in Table 5. The shot data sheets and plate photographs are provided in the Appendix.

Table 4 V_{50} results for 30-mm APDS projectile

LAT shot no.	Vs (m/s)	Result	Pitch (deg)	Yaw (deg)	Gamma (deg)	Powder grains	Remarks
15797	1100	CP	-0.39	-0.15	0.42	165	
15798	1013	PP	-1.46	0.13	1.47	145	
15799	1062	CP	-0.61	-1.01	1.18	155	
15800	1027	PP	-0.07	0.27	0.28	147	
15801	1037	CP	-0.49	0.40	0.63	150	
15802	1033	PP	0.57	-0.07	0.57	149	
15803	1036	CP	-0.18	-0.67	0.69	150	High partial Low complete

Table 5 Standard deviation for 30-mm APDS

4 shots	m/s
V_{50}	1033
Spread	10
Gap	3
ZMR	...
Std dev	5
Margin	1

The results from the 30-mm APDS threat show that the TIMET Ti108 exceeded the extrapolated minimum V_{50} requirement in MIL-DTL-46077G of 1032 m/s for a plate thickness of 3.1035 inches.

The V_{50} results for the 20-mm M602 AP-T projectile are given in Table 6 and the standard deviation in Table 7. The shot data sheets and plate photographs are provided in the Appendix.

Table 6 V_{50} results for 20-mm M602 AP-T projectile

LAT shot no.	Vs (m/s)	Result	Pitch (deg)	Yaw (deg)	Gamma (deg)	Powder grains	Remarks
15872	1044	CP	0.83	0.40	0.92	750	
15873	1006	CP	0.43	-1.50	1.56	700	
15874	965	PP	0.76	-0.03	0.76	650	
15875	977	PP	0.10	1.62	1.62	665	
15876	997	PP	-1.28	-1.47	1.95	685	High partial
15877	993	PP	-0.15	-2.93	2.93	690	
15878	1004	CP	-0.51	0.01	0.51	700	Low complete
15879	...	CP	...	...	...	690	No X-rays
15880	...	PP	...	...	...	683	No X-rays
15881	993	PP	2.12	-0.32	2.15	683	

Table 7 Standard deviation for 20-mm M602 AP-T projectile

4 shots	m/s
V_{50}	1000
Spread	13
Gap	7
ZMR	...
Std dev	6
Margin	-19

The results from the 20-mm M602 AP-T threat show that the TIMET Ti108 did not meet the minimum V_{50} requirements in MIL-DTL-46077G of 1019 m/s for a plate thickness of 3.1035 inches.

4. Conclusions

The TIMET Ti108 did not meet the minimum V_{50} requirement per the threat given as outlined in this experiment under the MIL-DTL-46077G standard. The Ti108 did exceed the extrapolated requirement for the 30-mm APDS by 1 m/s, but performed under the requirement for the 20-mm AP-T by 19 m/s. Due to close proximity in velocity of meeting the minimum required V_{50} standard, perhaps in the future additional studies or adjustments to the chemistry of the Ti108 can be conducted to optimize performance.

5. References

1. MIL-STD-662F. V₅₀ ballistic test for armor. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 1997 Dec 18.
2. Grabarek C, Herr E. X-ray multi-flash system for measurement of projectile performance at the target. Aberdeen Proving Ground (MD): Ballistic Research Laboratory (US); 1966. Report No.: BRL-TN-1634.
3. MIL-DTL-46077G (w/ amendment 1). Armor plate, titanium alloy, weldable. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2017 Jan 26.

Appendix. Shot Sheets and Postimpact Photographs

A.1 30-mm APDS Shot Sheets and Photos

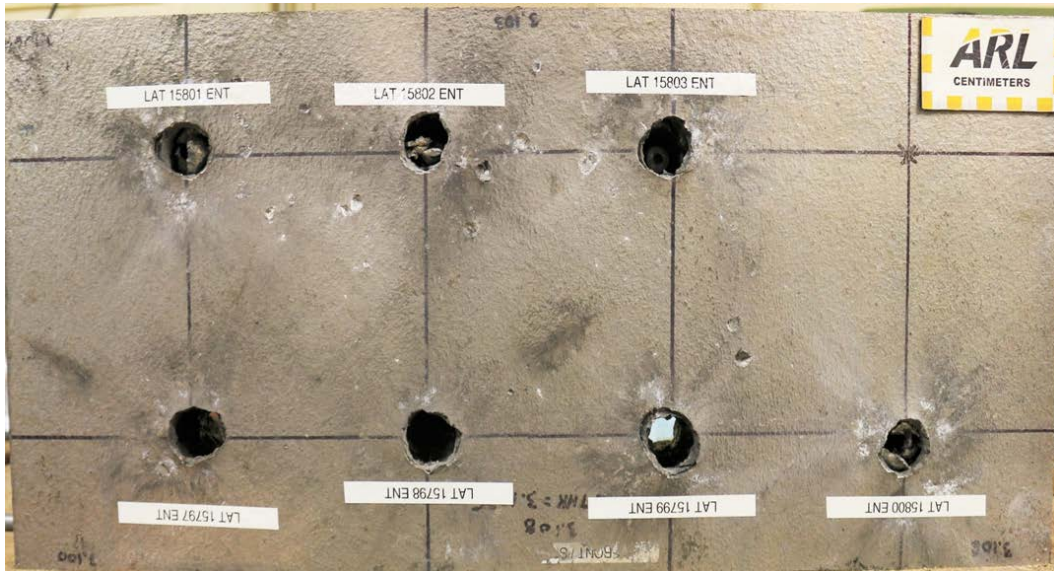


Fig. A-1 30-mm APDS overall front of plate (strike face)



Fig. A-2 30-mm APDS overall back of plate

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15797		Date:	6/26/2017		Range:	G	
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	56"				
Launch Package:			Case Size:		37mm	Powder Type:	165mm				
	Length	Diam	Mass	Primer Type:		M38B2	Powder Weight:	165 grams			
Penetrator			213.83	Expected Velocity:		1007 m/s	Shot Time:	919			
Sabot			14.52	Results							
Pusher			11.53	Velocity:	m/s	f/s	Residual	m/s	f/s		
Obturator			12.47		1100	3609	Velocity:				
Total (grams)			252.59								
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.39	Yaw:	-0.15	Total Yaw	0.42	
Velocity:			X								
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	16"	8"									
Preset	403.5	201.5									
Actual	404.1	202.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286	
2	Air					6"					
3	Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	3.3	3.7	2.2	2.4	6..6	7.5					
2											
3											
4											
5											
6											
7											
8											
Notes:											



<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15798		Date:	6/26/2017		Range:	G	
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	56"				
Launch Package:			Case Size:		37mm		Powder Type:	165mm			
	Length	Diam	Mass	Primer Type:		M38B2		Powder Weight:	145 grams		
Penetrator			213.27	Expected Velocity:		1007 m/s		Shot Time:	1022		
Sabot			14.48	Results							
Pusher			11.48	Velocity:	m/s	f/s	Residual	m/s	f/s		
Obturator			12.7		1013	3324	Velocity:				
Total (grams)			252.1								
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-1.46	Yaw:	0.13	Total Yaw	1.47	
Velocity:				X							
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	16"	8"									
Preset	403.5	201.5									
Actual	404.1	202.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286	
2	Air					6"					
3	Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	3.4	3.8					1	6.9	7.2		
2											
3											
4											
5											
6											
7											
8											
Notes:											



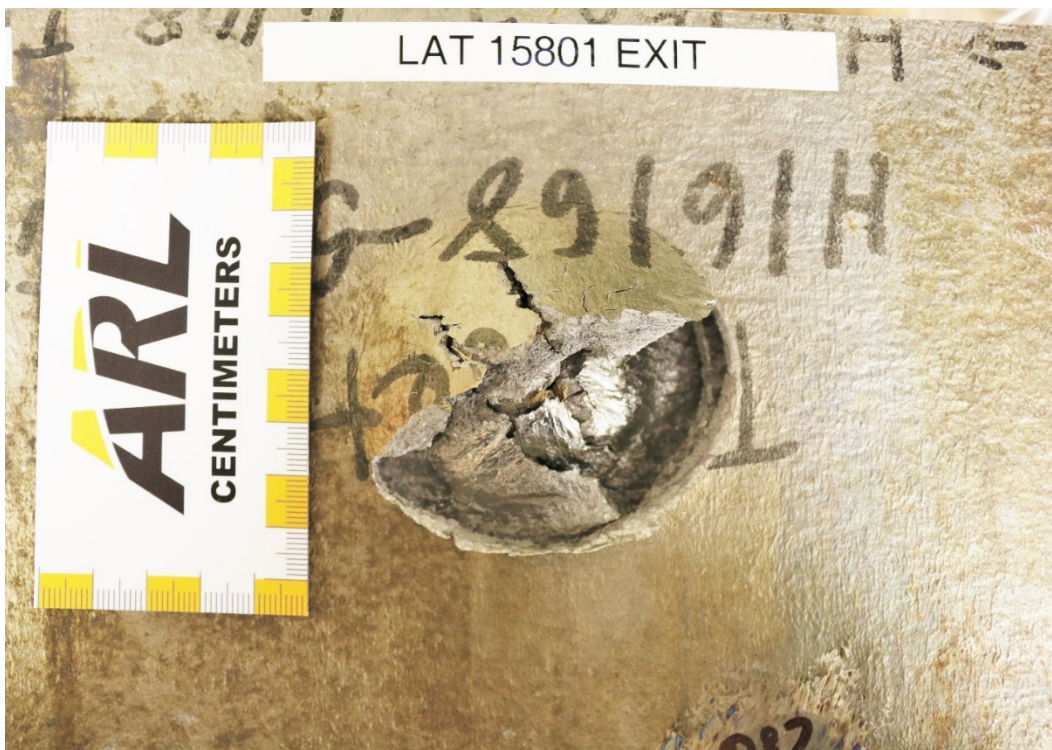
<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15799		Date:	6/26/2017		Range:	G	
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	140.5"				
Launch Package:			Case Size:		37mm		Powder Type:	165mm			
	Length	Diam	Mass	Primer Type:		M38B2		Powder Weight:	155 grams		
Penetrator			213.88	Expected Velocity:		1050 m/s		Shot Time:	1115		
Sabot			14.24	Results							
Pusher			11.41	Velocity:	m/s	f/s	Residual	m/s	f/s		
Obturator			12.48		1062	3485	Velocity:				
Total (grams)			252.28								
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.61	Yaw:	-1.01	Total Yaw	1.18	
Velocity:			X								
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	16"	8"									
Preset	387.5	193.5									
Actual	308.1	194.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286	
2	Air					6"					
3	Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	3.6	3.7	2.3	2.7	6.8	7.4					
2											
3											
4											
5											
6											
7											
8											
Notes:											



<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15800		Date:	6/26/2017		Range:	G	
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	140.5"				
Launch Package:			Case Size:		37mm		Powder Type:	165mm			
	Length	Diam	Mass	Primer Type:		M38B2		Powder Weight:	147 grams		
Penetrator			213.84	Expected Velocity:		1025 m/s		Shot Time:	1336		
Sabot			14.52	Results							
Pusher			11.47	Velocity:	m/s	f/s	Residual	m/s	f/s		
Obturator			12.48		1027	3368	Velocity:				
Total (grams)			252.63								
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.07	Yaw:	0.27	Total Yaw	0.28	
Velocity:				X							
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	16"	8"									
Preset	396.5	198.5									
Actual	397.2	199.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286	
2	Air					6"					
3	Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	3.2	3.2					1.1	6.6	7.2		
2											
3											
4											
5											
6											
7											
8											
Notes:											



<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15801		Date:	6/26/2017		Range:	G	
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	140.5"				
Launch Package:			Case Size:		37mm	Powder Type:	165mm				
	Length	Diam	Mass	Primer Type:		M38B2	Powder Weight:	150 grams			
Penetrator			212.82	Expected Velocity:		1045 m/s	Shot Time:	1431			
Sabot			14.52	Results							
Pusher			11.42	Velocity:	m/s	f/s	Residual	m/s	f/s		
Obturator			12.46		1037	3401	Velocity:				
Total (grams)			251.5								
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.49	Yaw:	0.4	Total Yaw	0.63	
Velocity:			X								
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	16"	8"									
Preset	388.5	194.5									
Actual	389.1	195.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286	
2	Air					6"					
3	Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	3	4.1			4.5	6.4					
2											
3											
4											
5											
6											
7											
8											
Notes:											



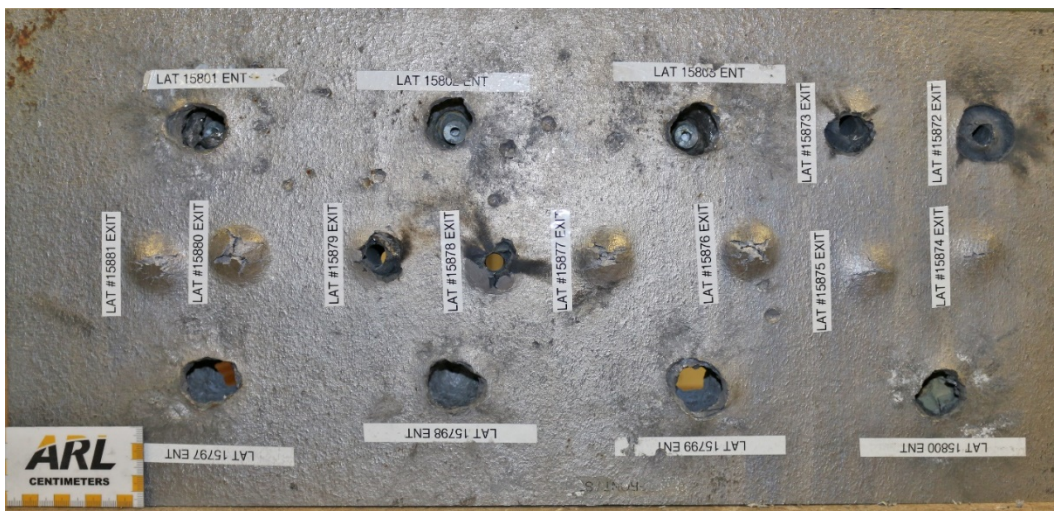
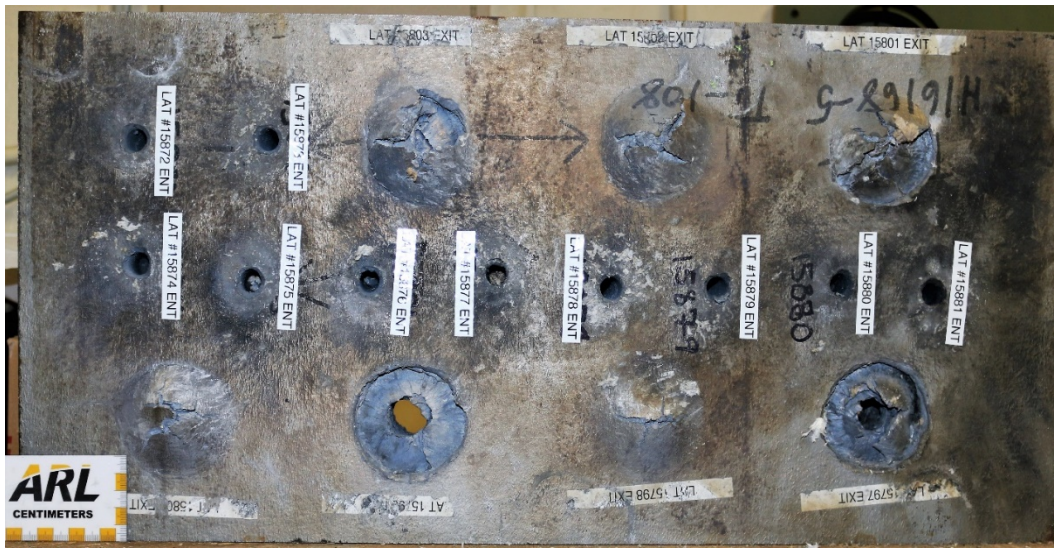
<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> </div>											
Program:	LAT		Shot #:	15802		Date:	6/27/2017		Range:	G	
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	140.5"				
Launch Package:			Case Size:		37mm	Powder Type:	165mm				
	Length	Diam	Mass	Primer Type:		M38B2	Powder Weight:	149 grams			
Penetrator			213.44	Expected Velocity:		1030 m/s	Shot Time:	635			
Sabot			14.55	Results							
Pusher			11.46	Velocity:	m/s	f/s	Residual	m/s	f/s		
Obturator			12.54		1033	3390	Velocity:				
Total (grams)			252.18								
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	0.57	Yaw:	-0.07	Total Yaw	0.57	
Velocity:				X							
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	16"	8"									
Preset	394.5	197.5									
Actual	395.1	198.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286	
2	Air					6"					
3	Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	3.4	3.1					1.5	6.8	7		
2											
3											
4											
5											
6											
7											
8											
Notes:											



ARL		EF-110 SHOT SHEET										ARL	
Program:	LAT		Shot #:	15803		Date:	6/27/2017		Range:	G			
Engineer:	Matt Burkins		Projectile:	30mm APDS		Gun:	#2 10' 1.090						
Test Director:		Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	140.5"					
Launch Package:				Case Size:	37mm		Powder Type:	165mm					
	Length	Diam	Mass	Primer Type:	M38B2		Powder Weight:	150 grams					
Penetrator			213.59	Expected Velocity:	1040 m/s		Shot Time:	719					
Sabot			14.43	Results									
Pusher			11.37										
Obturator			12.5	Velocity:	m/s	f/s	Residual	m/s	f/s				
					1036	3399	Velocity:						
Total (grams)			252.17										
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.18	Yaw:	-0.67	Total Yaw	0.69			
Velocity:			X										
X-Ray Times													
Tube Heads	1	2	3	4	5	6	7	8	9	10			
Distance	16"	8"											
Preset	390.5	195.5											
Actual	391.1	196.2											
Target Data													
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN			
1	Ti Mex H16168-5 Ti-108					3.1035"	0			286			
2	Air					6"							
3	Witness					.020"							
4													
5													
6													
7													
8													
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)			
	Length	Width	Length	Width	Length	Width	Height	Length	Width				
1	3.4	3.2			3.9	3.8							
2													
3													
4													
5													
6													
7													
8													
Notes:													



A.2 20-mm M602 AP-T Shot Sheets and Photos



<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15872		Date:	12/4/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package:			Case Size:		25mm	Powder Type:		37mm			
	Length	Diam	Mass	Primer Type:		M36A2	Powder Weight:		750 grains		
Penetrator			110.56	Expected Velocity m/s:		1050	Shot Time:		1125		
Sabot											
Pusher			Results								
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s		
Total (grams)			110.56		1044	3426	Velocity:				
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:			X		Pitch:	0.83	Yaw:	0.4	Total Yaw	0.92	
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	362.8	193.5									
Actual	363.2	194.3									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.9	1.8	1.3	1.5	3.1	3.5					
2											
3											
4											
5											
6											
7											
8											
Notes:											

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15873		Date:	12/4/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package:			Case Size:		25mm	Powder Type:		37mm			
	Length	Diam	Mass	Primer Type:		M36A2	Powder Weight:		700 grains		
Penetrator			110.32	Expected Velocity m/s:		1000	Shot Time:		1340		
Sabot											
Pusher			Results								
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s		
Total (grams)			110.32		1006	3300	Velocity:				
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:			X		Pitch:	0.43	Yaw:	-1.5	Total Yaw	1.56	
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	381.0	203.2									
Actual	382.2	204.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.9	1.7	1.3	1.1	3.2	2.4					
2											
3											
4											
5											
6											
7											
8											
Notes:											

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15874		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package:			Case Size:		25mm	Powder Type:	37mm				
	Length	Diam	Mass	Primer Type:		M36A2	Powder Weight:	650 grains			
Penetrator			110.55	Expected Velocity m/s:		950	Shot Time:	626			
Sabot											
Pusher											
Obturator				Results							
Total (grams)			110.55	Velocity:	m/s	f/s	Residual	m/s	f/s		
				965	3165	Velocity:					
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:				X	Pitch:	0.76	Yaw:	-0.03	Total Yaw	0.76	
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	401.0	213.9									
Actual	402.2	214.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.9	1.8					0.3	3.6	4.2		
2											
3											
4											
5											
6											
7											
8											
Notes:											

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15875		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package:			Case Size:		25mm	Powder Type:	37mm				
	Length	Diam	Mass	Primer Type:		M36A2	Powder Weight:	665 grains			
Penetrator			110.39	Expected Velocity m/s:		985	Shot Time:	720			
Sabot											
Pusher				Results							
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s		
Total (grams)			110.39		977	3206	Velocity:				
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:				X	Pitch:	0.1	Yaw:	1.62	Total Yaw	1.62	
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	386.8	206.3									
Actual	387.2	207.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	2	1.8					0.5	4	4.3		
2											
3											
4											
5											
6											
7											
8											
Notes:											

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15876		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8' 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package:			Case Size:		25mm	Powder Type:	37mm				
	Length	Diam	Mass	Primer Type:		M36A2	Powder Weight:	685 grains			
Penetrator			110.31	Expected Velocity m/s:		990	Shot Time:	920			
Sabot											
Pusher			Results								
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s		
Total (grams)			110.31	Velocity:	997	3270	Velocity:				
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:				X	Pitch:	-1.28	Yaw:	-1.47	Total Yaw	1.95	
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	384.8	205.2									
Actual	385.2	206.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.8	1.9					1.1	4	4.1		
2											
3											
4											
5											
6											
7											
8											
Notes:											

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15877		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package				Case Size:	25mm		Powder Type:	37mm			
	Length	Diam	Mass	Primer Type:	M36A2		Powder Weight:	690 grains			
Penetrator			110.18	Expected Velocity m/s:	1000		Shot Time:	1037			
Sabot											
Pusher											
Obturator				Results							
Total (grams)			110.18	Velocity:	m/s	f/s	Residual	m/s	f/s		
				993	3257	Velocity:					
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:			X	Pitch:	-0.15	Yaw:	-2.93	Total Yaw	2.93		
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	381.0	203.2									
Actual	382.2	204.3									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.8	1.8					1	4.2	4		
2											
3											
4											
5											
6											
7											
8											

Notes:

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15878		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package				Case Size:	25mm		Powder Type:	37mm			
	Length	Diam	Mass	Primer Type:	M36A2		Powder Weight:	700 grains			
Penetrator			110.67	Expected Velocity m/s:	1005		Shot Time:	1122			
Sabot											
Pusher											
Obturator				Results							
Total (grams)			110.67	Velocity:	m/s	f/s	Residual	m/s	f/s		
				1004	3293	Velocity:					
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:			X		Pitch:	-0.51	Yaw:	0.01	Total Yaw	0.51	
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	379.1	202.2									
Actual	380.2	203.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.8	1.6			1.5	2.1					
2											
3											
4											
5											
6											
7											
8											

Notes:

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15879		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package				Case Size:	25mm		Powder Type:	37mm			
	Length	Diam	Mass	Primer Type:	M36A2		Powder Weight:	690 grains			
Penetrator			110.36	Expected Velocity m/s:	995		Shot Time:	1259			
Sabot											
Pusher											
Obturator				Results							
Total (grams)			110.36	Velocity:	m/s	f/s	Residual	m/s	f/s		
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:			X	Pitch:			Yaw:	Total Yaw:			
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	382.9	204.2									
Actual	383.2	205.2									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.6	1.7			1.4	2.3					
2											
3											
4											
5											
6											
7											
8											
Notes:											
No X-rays trigger wire was fraged.											

<div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div>											
Program:	LAT		Shot #:	15880		Date:	12/5/2017		Range:	G	
Engineer:	John Hogan		Projectile:	M602		Gun:	#ED5 8" 20mm (Rifled)				
Test Director:	Hugh Walter		Gunner:	David Handshoe		Muzzle to Target:	61.25"				
Launch Package				Case Size:	25mm		Powder Type:	37mm			
	Length	Diam	Mass	Primer Type:	M36A2		Powder Weight:	683 grains			
Penetrator			110.59	Expected Velocity m/s:	990		Shot Time:	1340			
Sabot											
Pusher											
Obturator				Results							
Total (grams)			110.59	Velocity:	m/s	f/s	Residual	m/s	f/s		
Phantom	m/s	f/s	Complete:	Partial:							
Velocity:				X	Pitch:		Yaw:	Total Yaw:			
X-Ray Times											
Tube Heads	1	2	3	4	5	6	7	8	9	10	
Distance	15	8									
Preset	384.8	205.2									
Actual	385.2	206.3									
Target Data											
Plate #	Material					Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108					3.1035"	0				
2	Air					6"					
3	AL Witness					.020"					
4											
5											
6											
7											
8											
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)	
	Length	Width	Length	Width	Length	Width	Height	Length	Width		
1	1.6	1.8					1	4	4.2		
2											
3											
4											
5											
6											
7											
8											

Notes:

No X-rays frags in trigger screen holder.



EF-110 SHOT SHEET



Program:	LAT	Shot #:	15881	Date:	12/6/2017	Range:	G			
Engineer:	John Hogan	Projectile:	M602	Gun:	#ED5 8' 20mm (Rifled)					
Test Director:	Hugh Walter	Gunner:	David Handshoe	Muzzle to Target:	61.25"					
Launch Package			Case Size:	25mm	Powder Type:	37mm				
	Length	Diam	Mass	Primer Type:	M36A2	Powder Weight:	683 grains			
Penetrator			110.4	Expected Velocity m/s:	990	Shot Time:	723			
Sabot										
Pusher				Results						
Obturator				Velocity:	m/s	f/s	Residual			
Total (grams)			110.4		993	3257	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:			X	Pitch:	2.12	Yaw:	-0.32			
			Total Yaw	2.15						
X-Ray Times										
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	384.8	205.2								
Actual	385.2	206.2								
Target Data										
Plate #	Material				Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN	
1	Ti Mex H16168-5 Ti-108				3.1035"	0				
2	Air				6"					
3	AL Witness				.020"					
4										
5										
6										
7										
8										
Plate #	Entrance Hole (cm)		Center Hole (cm)		Exit Hole (cm)		Bulge (cm)			Pene (cm)
	Length	Width	Length	Width	Length	Width	Height	Length	Width	
1	1.8	1.7					0.9	3.6	4.1	
2										
3										
4										
5										
6										
7										
8										

Notes:

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List of Symbols, Abbreviations, and Acronyms

APDS	armor piercing discarding sabot
AP-T	armor piercing with tracer
ARL	US Army Research Laboratory
CP	complete penetration
HBW	Brinell hardness
LAT	light armor technologies
PP	partial penetration
TIMET	Titanium Metals Corporation
ZMR	zone of mixed results

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